Farmer Efficiency and Technology Use with Age

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Productivity of U.S. farmers by age is measured by non-parametric programming using 1992 Census data, decomposed into efficiency and technology Malmquist index components. Productivity increases slightly with age and then decreases. In most states productivity variations are from technology use rather than efficiency differences.

Common belief and some empirical evidence indicates that productivity of a farmer may increase with age, reach some maximum level, and then decrease with further age (Tauer 1984; Tauer 1995). If productivity exhibits a life-cycle pattern, then productivity of agriculture may decrease as the U.S. farm population continues to age. Life-cycle changes are also critical in planning for succession of farms to the next generation, where transfers should occur near peaks in productivity.

Previous estimates of U.S. farmer productivity by age did not decompose productivity into efficiency and technology components, but if productivity changes with age, decomposition would be useful. Efforts aimed at alleviating productivity decreases or enhancing productivity increases would depend upon whether productivity changes were from efficiency or technology use. Productivity might first increase with age if efficiency increases as a farmer gains experience. Productivity may decrease with old age as a farmer fails to adopt new technology. Younger farmers could be provided with incentives to participate in educational and training programs, enhancing their efficiency. Older farmers might be allowed to accelerate investment write-offs for taxes, encouraging investment.

This research estimates productivity of farmers by age for each state by computing separate efficiency and technology components. Productivity is the product of efficiency and technology indices. These Malmquist indices are computed using non-parametric linear programming. A primal specification is used so that no assumption is necessary concerning cost or profit optimization behavior. The non-parametric approach also requires no functional specification for the technology. Since the approach estimates efficiency and technology use relative to a reference set of farms, a consistent reference set is constructed by placing each state into one of four regional groups. The technology use and efficiency of that state is then measured relative to its regional reference set.

Measuring Productivity

Productivity difference between firms is measured by the difference in the ratio of outputs to inputs used in a production process. Since multiple inputs and outputs are involved in a production process, various procedures have been developed to aggregate inputs and outputs and to measure differences. The Malmquist index, formulated by Caves, Christensen and Diewert in 1982, has been recently developed within the nonparametric or Data Envelopment Analysis (DEA) framework by Färe et al. 1990. The technique has been used to measure the productivity of countries (Färe et al. 1994), electric utilities (Hjalmarsson and Veiderpass), the natural gas industry (Price and Weyman-Jones), and agriculture (Fulginiti and Perrin). Most of these articles present graphics to illustrate the Malmquist index. A book length treatment is Färe, Grosskopf and Lovell.

The approach utilizes distance functions and can be used to measure technical and efficiency differences in a firm over time or between firms at a point in time. Here we measure differences be-

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tween firms at a point in time. A firm in this paper is defined as farmers in a specific age group. Hence, we will be measuring technical and efficiency differences between farmers of different ages at a point in time.

An output distance function can be defined for an age group k as (Cornes 1992):

(1) $D_o^k(x^k, y^k) = (\max\{\theta:(x^k, \theta y^k) \in s^k\})^{-1}$.

This essentially shows how much output(s) y can be increased given a quantity of input(s) x, such that x and θy remain in the production set. An input distance function can similarly be defined and under constant returns its value is the reciprocal to the output distance function. An output rather than an input distance function is used here since farmers more likely try to increase their outputs given their use of inputs, rather than try to decrease inputs given their outputs. The reference technology set s^k consists of observations of farmers of the same age group from various regions (states).

To construct the Malmquist index, it is necessary to define distance functions with respect to two different age groups k and $k + 1$ as:

(2) $$D_o^k(x^{k+1}, y^{k+1}) = (\max\{\theta: (x^{k+1}, \theta y^{k+1}) \in s^k\})^{-1}$$

and

(3) $D_o^{k+1}(x^k, y^k) = (\max\{\theta: (x^k, \theta y^k) \in s^{k+1}\})^{-1}$.

The distance function specified by equation (2) measures the maximal proportional change in output required to make (x^{k+1}, y^{k+1}) feasible in relation to the technology used by age group k. Similarly, the distance function specified by equation (3) measures the maximal proportional change in output required to make (x^k, y^k) feasible in relation to the technology set s^{k+1} used by age group $k + 1$.

Efficiency difference between age groups k and $k + 1$ is measured as:

$$E_o^{k+1}(y^{k+1},x^{k+1},y^k,x^k) = \frac{D_o^{k+1}(x^{k+1},y^{k+1})}{D_o^k(x^k,y^k)},$$

where the numerator is the distance function, equation (1), measured for age $k + 1$.

Technical difference between age k and $k + 1$ is measured as:

$$T_o^{k+1}(y^{k+1},x^{k+1},y^k,x^k) = \left[\left(\frac{D_o^k(x^{k+1},y^{k+1})}{D_o^{k+1}(x^k,y^k)}\right)x\left(\frac{D_o^k(x^k,y^k)}{D_o^{k+1}(x^{k+1},y^{k+1})}\right)\right]^{1/2}.$$

The Malmquist productivity index is the product of the efficiency index and the technical index, $M_o^{k+1}(.) = E_o^{k+1}(.) \bullet T_o^{k+1}(.)$.

These defined distance functions are reciprocals to the output-based Farrell measure of technical efficiency and can be calculated for each age group using nonparametric programming techniques (Färe et al. 1994). The linear programming model to calculate the output distance function (1) for each of the k firms in an age group is:

(5) $$(D_o^k(x^{k'},y^{k'}))^{-1} = \max \theta^{k'}$$

subject to

(5.a) $$\sum_{k=1}^{K} Z^k y_m^k \geq \theta^{k'} y_m^{k'} \qquad m = 1, \ldots, M$$

$$\sum_{k=1}^{K} z^k x_n^k \leq x_n^{k'} \qquad n = 1, \ldots, N$$

(5.b) $$z^k \geq 0 \qquad k = 1, \ldots, K$$

where z is the intensity vector, y is output, x is input, θ is the inverse of the efficiency score, M is the number of outputs, N is the number of inputs, and K is the number of firms. The technology specified here is nonparametric but assumes constant returns to scale and strong disposability of inputs and outputs. The nonparametric computation of $D_o^{k+1}(x^{k+1}, y^{k+1})$ is exactly like (5), where $k + 1$ is substituted for k.

The two distance functions specified in equations (2) and (3) require data from two different age groups. The first is computed for age group k as:

(6) $$(D_o^k(x^{k'+1},y^{k'+1}))^{-1} = \max \theta^{k'}$$

subject to

$$\sum_{k=1}^{K} z^k y_m^k \geq \theta^{k'} y_m^{k'+1} \qquad m = 1, \ldots, M$$

$$n = 1, \ldots, N$$

$$\sum_{k=1}^{K} z^k x_n^k \leq x_n^{k'+1} \qquad k = 1, \ldots, K$$

$$z^k \geq 0$$

The second is specified as in (6), but the k and k + 1 superscripts are transposed.

In linear program models (5), (6) and the transpose of (6) each member of the Z vector is bounded below by zero imposing only constant returns. To impose decreasing returns, the constraint $\sum_{k=1}^{K} z^k \leq 1$ is added to the program. To impose non-constant returns, the constraint

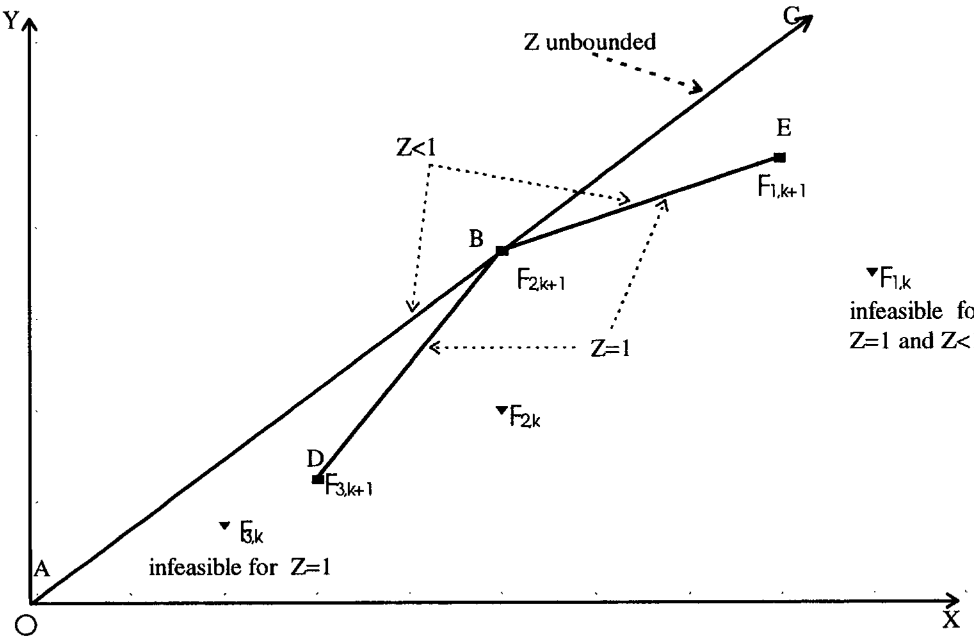

Figure 1. Infeasibilities When Measuring Productivity Relative to Two Distinct Groups Under Non-Constant Returns

$\sum_{k=1}^{K} z^k = 1$ is added instead. Since farm size may vary by age, it would be informative to ascertain the role of scale in productivity differences between age groups. Unfortunately, imposing anything but non-constant returns in program (6) or its transpose can result in infeasible solutions. This problem is discussed by Ray and Mukherjee 1996, and Färe and Mitchell 1987.

When the productivity of a firm in one group (or period) is measured relative to the production set specified by the netputs of the firms from another group (period) using linear programming, it is possible to obtain infeasible solutions when the returns to scale are not constant. This is illustrated in figure 1 where a single input and output is graphed for three firms in group k ($F_{1,k}$, $F_{2,k}$, and $F_{3,k}$) and for three firms in group k + 1 ($F_{1,k+1}$, $F_{2,k+1}$, and $F_{3,k+1}$). With constant returns to scale defined for group k + 1, and implemented by no constraint on the Z vector in the linear program, the production frontier is defined by line ABC. Any output or input distance function for any firm in period k is defined relative to this line because it is possible to draw any verticle (output) or horizontal (input) line from firms $F_{1,k}$, $F_{2,k}$, or $F_{3,k}$ to the line segment ABC.

If decreasing returns to scale are defined for group k + 1, implemented by the restriction $\sum_{k=1}^{K} z^k \leq 1$, then the production frontier becomes the line segments ABE. The frontier cannot be extended beyond point E. It is clear that the output distance function from firm $F_{1,k}$ relative to this frontier ABE is not defined, and therefore the program would be infeasible since a vertical line drawn from firm $F_{1,k}$ does not reach the line segment ADE. It is true, however, that the input distance function for firm $F_{1,k}$ relative to ABE would be defined since a horizontal line from firm $F_{1,k}$ can be drawn to ABE. If nonconstant returns (increasing and then decreasing) is defined, implemented by the restriction $\sum_{k=1}^{K} z^k = 1$, then the production frontier becomes DBE. In this case neither the output or the input distance function is defined for firm $F_{3,k}$ relative to this production frontier.

Data

Data from the 1992 Census of Agriculture (U.S. Department of Commerce) are used to estimate efficiency, technology, and productivity between age groups within each state. Census data are summarized by state into six age groups: under 25 years of age, 25 to 34 years, 35 to 44 years, 55 to 64 years, and over 65 years. The data from farmers over 65 years of age were not used since Tauer (1984) surmised that as a group these farmers are liquidating assets, such as breeding stock, resulting in large measured outputs relative to measured inputs. The data for some age groups were not available due to non-disclosure rules in Alaska, Hawaii, Nevada, and New Hampshire, so those states were excluded from the analysis. Rhode Island was also excluded.

Using one output and five input variables described below, the distance functions were calculated via linear programming methods using GAMS/MINOS. The scalar values from those distance functions were used to calculate indexes for efficiency, technical, and productivity differences across age groups within a state.

The output variable is the sum of the market value of agricultural products sold, plus other farm-related income, and direct government payments. Although some of these government payments are strictly transfer payments, most require farmers to alter production. Since it was not possible to separate out payments that are strictly transfer, all government payments for an age group were included in output. Expenses were grouped into five categories and are used as input variables. These are livestock expenses, crop production expenses, energy and petroleum expenses, labor expenses, and operator labor. All the variables use average per farm values for each age cohort.

Livestock expenses were livestock and poultry purchases, plus feed for livestock and poultry. Fertilizer, chemicals, and seed, bulb, plant and tree purchases, land and building, machinery and equipment, repair and maintenance expenses were grouped together in the category crop and production expenses. The value of land and building, and value of machinery and equipment are reported in the Census as average values per farm for each age cohort. To estimate the input flow from these assets the average value of land and building was multiplied by 10% reflecting average rent value in agriculture, and the average value of machinery and equipment was multiplied by 20% to reflect a depreciation rate of 15% and interest rate of 5%. All energy and petroleum expenses were included as an energy input.

Hired farm labor, contract labor and custom work hired were grouped together as a labor input. To reflect the family labor expense that was not paid a wage, the data on operator labor reported in the Census were used. The data on operator labor are the number of days of work off the farm, grouped by number of respondents into four categories: none, 1 to 99 days, 100 to 199 days, and 200 days or more. An average composite of hours worked on the farm for each age cohort was computed by subtracting from an assumed 250 days available, a weighting of the number of respondents in each of the four age groups by their respective means—0 days, 50 days, 150 days, and 250 days—and then dividing by the total number of respondents.

The efficiency, technological and productivity indexes were estimated relative to states in the same region. Four regions were constructed by combining the ten USDA defined production regions for the United States. The states were grouped into the following regions; Group 1, Northeast: Connecticut(CT), Delaware(DE), Maine(ME), Maryland(MD), Massachusetts(MA), New Jersey(NJ), New York(NY), Pennsylvania(PA), Rhode Island(RI), Vermont(VT). Group 2, Midwest: Illinois(IL), Indiana(IN), Iowa(IA), Kansas(KS), Michigan(MI), Minnesota(MN), Missouri(MO), Nebraska(NE), North Dakota(ND), Ohio(OH), South Dakota(SD), Wisconsin(WI). Group 3, West: Arizona(AZ), California(CA), Colorado(CO), Idaho(ID), Montana(MT), New Mexico(NM), Oklahoma(OK), Oregon(OR), Texas(TX), Utah(UT), Washington(WA), Wyoming(WY). Group 4, Southeast: Alabama(AL), Arkansas(AR), Florida(FL), Georgia(GA), Kentucky(KY), Louisiana(LA), Mississippi(MS), North Carolina(NC), South Carolina(SC), Tennessee(TN), Virginia(VA), West Virginia(WV).

Results

Table 1 shows the productivity and the technology index of each age group by state. The efficiency index for each age group by state can be calculated by dividing the productivity index by the technology index. Within each state the productivity and technology index of the age group "under 25 years" was used as the base for that state, so by default it has an index value of 1.00 and is not shown. Other ages within that state is thus indexed relative to the "under 25 age group." This indexing precludes comparison of efficiency across states, since "absolute" productivity and technology use are different for the base groups for different states.

Results generally show that productivity of U.S. farmers increases slightly with age and then decreases, although there is significant variation by state. In California (CA) for instance, the productivity of farmers aged 25 to 34, is 6% greater than farmers under age 25. Farmers aged 35 to 44 are 7% more productive, those aged 45 to 54 are 6% more productive, and those aged 55 to 64 are 8% less productive than those farmers that are under age 25. These numbers for the largest agricultural state (total receipts) clearly show a life-cycle phenomenon, where the productivity of farmers increases with age, reaches a maximum, and finally

Table 1. Farmer Productivity and Technology Indexes by Age*

	Age 25–34		Age 35–44		Age 45–54		Age 55–64	
State	Prod.	Tech.	Prod.	Tech.	Prod.	Tech.	Prod.	Tech.
				Northeast				
CT	1.13	1.13	0.75	0.77	1.45	1.45	1.31	1.31
DE	1.04	1.03	1.14	1.14	1.14	1.14	1.10	1.10
MA	1.08	1.06	1.10	1.07	1.16	1.14	1.06	1.04
MD	0.90	0.90	1.02	1.02	1.02	1.07	1.04	1.07
ME	0.93	0.95	1.03	1.03	1.07	1.07	0.96	0.96
NJ	1.38	1.26	0.97	0.89	1.12	1.02	1.11	1.02
NY	1.21	1.13	1.05	0.98	1.10	1.05	1.07	1.00
PA	1.04	1.04	1.05	1.05	1.07	1.07	1.08	1.08
VT	1.08	1.13	1.00	1.03	1.03	1.04	1.02	1.02
AVG	1.09	1.07	1.01	1.00	1.13	1.12	1.08	1.07
				Midwest				
IA	1.24	1.24	1.10	1.10	1.07	1.07	1.14	1.14
IL	1.18	1.18	1.09	1.09	1.11	1.11	1.03	1.03
IN	1.30	1.30	1.23	1.29	1.23	1.29	1.13	1.19
KS	1.41	1.41	1.32	1.32	1.31	1.31	1.09	1.09
MI	1.07	1.23	1.10	1.23	1.07	1.16	0.95	1.04
MN	1.05	1.15	1.05	1.17	1.05	1.14	1.03	1.14
MO	1.35	1.17	1.12	1.05	1.16	1.05	1.15	1.03
ND	1.22	1.22	1.09	1.09	1.13	1.13	1.05	1.05
NE	1.26	1.30	1.21	1.21	1.17	1.17	0.97	0.97
OH	1.26	1.17	1.15	1.09	1.15	1.06	1.10	1.04
SD	1.15	1.18	1.09	1.14	1.09	1.09	1.08	1.07
WI	1.12	1.12	1.10	1.03	1.03	0.98	1.06	0.99
AVG	1.22	1.22	1.14	1.15	1.13	1.13	1.07	1.06
				West				
AZ	0.81	0.81	1.14	1.14	1.12	1.12	1.17	1.17
CA	1.06	1.06	1.07	1.07	1.06	1.06	0.92	0.92
CO	1.56	1.16	1.35	1.00	1.34	1.00	1.19	0.89
ID	0.86	0.65	1.06	0.80	1.05	0.79	1.03	0.77
MT	0.79	0.79	0.96	0.96	0.94	0.94	0.89	0.89
NM	1.11	1.11	1.11	1.11	1.12	1.14	1.17	1.17
OK	1.24	1.24	1.07	1.07	1.11	1.11	1.12	1.12
OR	0.82	0.82	1.06	1.06	1.01	1.01	0.97	0.97
TX	1.01	1.07	1.01	1.02	1.03	1.03	1.02	1.01
UT	1.83	1.05	1.47	0.72	1.40	0.70	1.42	0.71
WA	1.31	1.27	1.23	1.02	1.21	1.00	1.22	1.01
WY	0.98	0.96	0.98	0.97	1.01	0.99	0.99	1.01
AVG	1.11	1.00	1.13	1.00	1.12	0.99	1.09	0.97
				Southeast				
AL	1.03	1.03	1.10	1.10	1.08	1.08	1.04	1.04
AR	1.04	1.04	0.97	0.97	1.02	1.02	0.91	0.91
FL	1.28	1.28	1.01	1.01	1.07	1.07	1.15	1.15
GA	1.09	1.09	1.09	1.09	1.05	1.05	0.88	0.91
KY	1.22	0.99	1.10	0.90	1.12	0.92	1.07	0.87
LA	0.75	0.75	0.96	0.96	0.93	0.93	0.92	0.92
MS	1.24	1.14	1.07	0.98	1.06	0.97	0.98	0.90
NC	1.15	1.06	1.12	1.03	1.12	1.03	0.96	0.89
SC	0.55	0.67	0.96	1.05	0.90	0.98	0.91	0.97
TN	0.95	0.95	0.97	0.98	1.03	1.05	1.01	1.01
VA	1.06	1.08	1.08	1.16	1.10	1.20	1.08	1.22
WV	0.72	0.86	1.10	1.10	0.91	0.96	0.99	1.06
AVG	1.01	1.00	1.04	1.03	1.03	1.02	0.99	0.99

*The age group "under 25" was used as the base, thus by default it has productivity and technology index 1.00 for each state. Farmer efficiency index can be calculated for each state and age group by dividing the productivity index by the corresponding technology index.

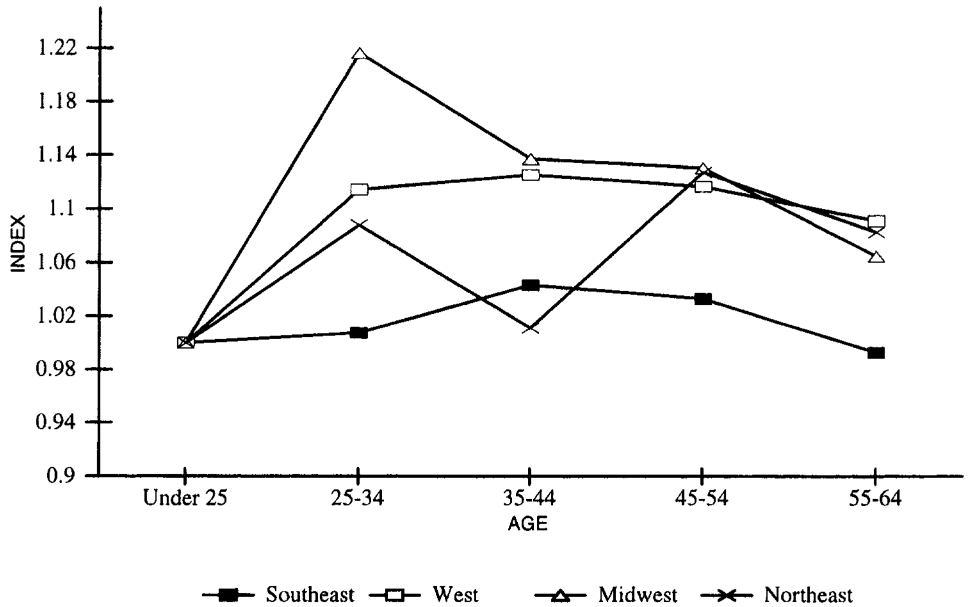

Figure 2. Productivity Index of Farmers by Age by Region

falls below the productivity of the youngest age group. In contrast, the productivity of the second age cohort in Montana (MT) drops by 21%, and although is partially restored with further age cohorts, always remains below 1.00.

Some numbers clearly appear to be outliers, since no discernible pattern by age is exhibited for that state. An example is South Carolina (SC), where productivity of the second age cohort drops to .55 compared to the productivity of 1.0 for the youngest age group. The productivity of successively older farmers in SC are then .96, .90, and .91, values less than one, but much greater than the second age cohort value of .55. Other states that appear to be outliers include Connecticut, Utah, Louisiana, and West Virginia.

Table 1 illustrates that in most states technology use by age rather than efficiency change by age was most responsible for productivity differences by age. However, significant variability exists by state. In Midwest states, productivity differences appear to be even more influenced from technology variation than for states in other regions. In those other regions, differences in efficiency are more significant determinants of productivity differences.

Average productivity by age for each region is shown in figure 2. It appears that for most of the states in the Midwest region, productivity peaks at age 25–34. In the West and Southeast regions, productivity appears to peak for most states at the later age group of 35–44, while in the Northeast productivity peaks at the age 45–54. The Midwest states show the most consistent life-cycle pattern. There generally appears to be first an increase in productivity in the second age cohort, but then a decrease and leveling of productivity in the third and fourth age cohorts, and another decrease in the fifth and last age cohort. In all states in the Midwest the productivity of the second age cohort, age 25–34, is greater than the productivity of the farmers under age 25. That is not the case for all states in the other regions. The Southeast shows the least consistent pattern in productivity changes. On average for states in that region, productivity increases slightly and then decreases with age, but there is significant variability by state.

Average technology use by age for each region is shown in figure 3. Technology displays a cyclical pattern in the Northeast with an increase, decrease, increase again, and then slight decrease. In both the West and Southeast it first decreases slightly, then increases, and then at the old age group decreases. The Midwest states display a more classic life cycle where technology first significantly increases and then tapers off as the farmer ages.

Average efficiency by age for each region is shown in figure 4. In the West region, efficiency peaks at age 25–34, then decreases slightly and stays level for the later age groups. The Northeast and Southeast states also exhibit a more gradual increase and then leveling of efficiency. All of these patterns are consistent with the belief that

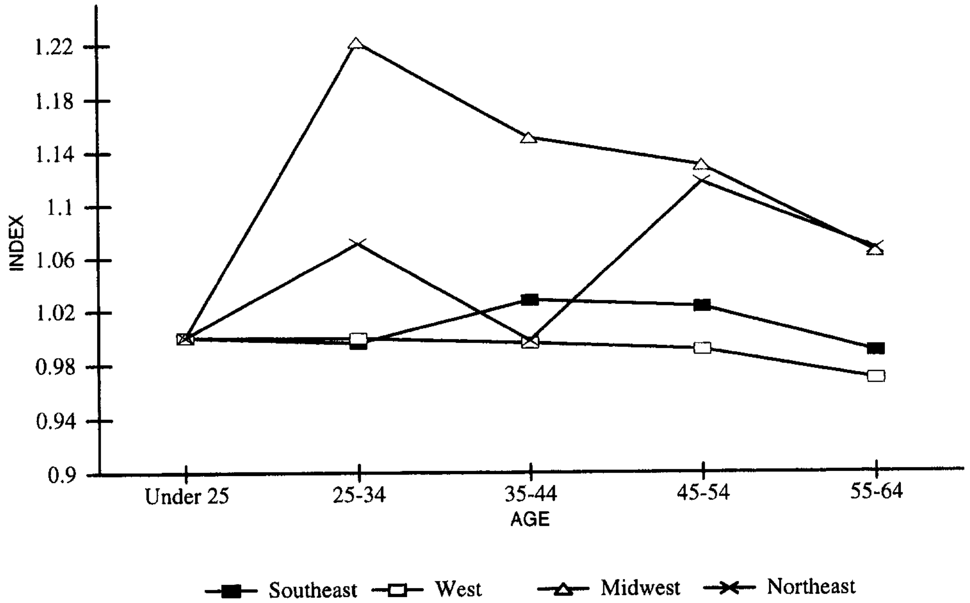

Figure 3. Technology Use Index of Farmers by Age by Region

farmers learn and become more efficient as they age. In contrast, the Midwest shows a very slight decrease, and then increase in efficiency, essentially a flat efficiency change over age. In a few states all age groups are technically efficient, which results in an efficient index of 1.0 for all age groups.

Conclusions

Differences in farmer efficiency, technology use, and productivity with age were computed as Malmquist indices using non-parametric programming. Data were state level observations for five different age cohorts from the 1992 Census of Ag-

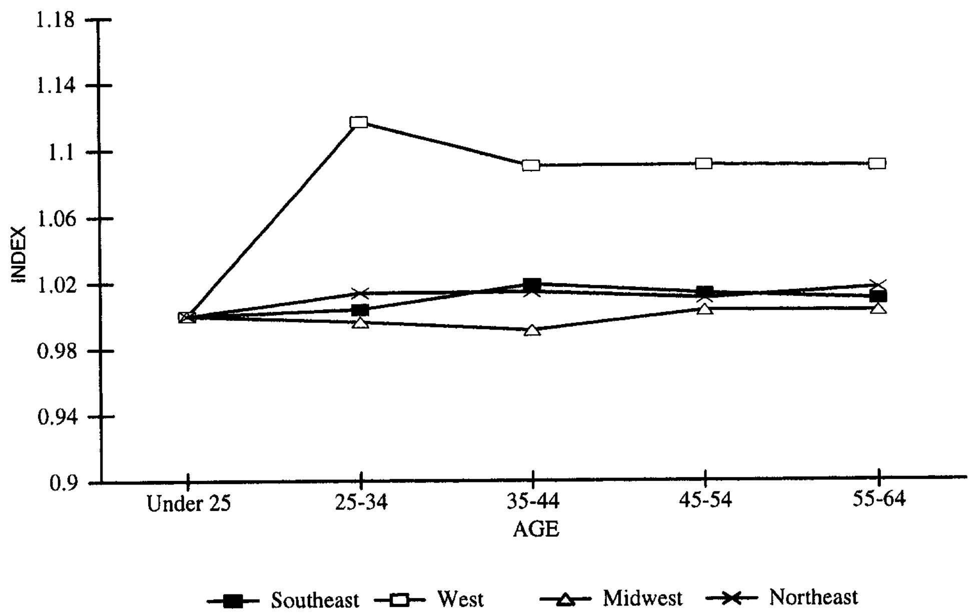

Figure 4. Efficiency Index of Farmers by Age by Region

riculture. The productivity of farmers appears to increase slightly and then decrease with age. Most change in productivity appears to be due to technology use by age, with enhanced technology use occurring at mid-life, although for many states there is also a slight increase and then decrease in efficiency by age.

Appropriate procedures to increase farmer productivity depend upon the age of the farmer. Programs aimed at younger farmers might address increasing their efficiencies, but programs to encourage or permit investment in new technology would increase productivity more in most regions. Although programs aimed at preventing the efficiencies of older farmers from dropping would also be useful, techniques to encourage continued investment as a farmer ages would better maintain productivity.

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